

2N MASK DESIGN AND METHOD OF SEQUENTIAL LATERAL
SOLIDIFICATION

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BACKGROUND OF THE INVENTION

The present invention relates to sequential lateral
5 solidification(SLS).

One method of SLS, which may be referred to as the "2-shot
process," has been investigated for use in high-throughput processes. In
this process, small beamlets, or a small beamlet, are projected onto
regions of a silicon film overlying another substrate to induce melting and
10 solidification(also referred to as "crystallization") of large-grained
polycrystalline silicon material. This may be referred to as a first shot.
The small beamlets are then advanced and the process repeated such that
the melted and solidified regions of this second shot overlap the regions of
the first shot.

15 This process may be accomplished by using a single array of
beamlets and making two or more passes over a given region of silicon
film and microtranslating the array between passes. The process may
also be accomplished by using multiple arrays of beamlets that are
staggered with respect to each other and scanning the entire pattern in a
20 across the silicon film. A single beamlet may also be used to iteratively
stitch together crystallized regions, although this offers poor throughput.

The material produced using the above described process has
severe directionality effects. The material has a plurality of narrow

rectangular crystal grains oriented with the long axis perpendicular to the beamlet length.

As these directional effects are generally undesirable, a 2 + 2 process may be used to reduce, or eliminate, these directional effects. This
5 may be accomplished by following up a first 2-shot process with a second 2-shot process carried out in a direction orthogonal to the first. This has been carried out by crystallizing silicon with an initial 2-shot process, rotating the sample being crystallized by 90 degrees, and then carrying out the second 2-shot process.

10 The need to rotate the sample by 90 degrees decreases throughput of the system, and adds complexity to the stage system for carrying out the SLS process.

SUMMARY OF THE INVENTION

Accordingly, a mask design is provided which enables a 2 + 2
15 process to be accomplished without the need to rotate the mask or the substrate relative to each other. This reduces the complexity of stages or mask mounts, and improves the angular alignment of the multiple 2-shot processes. The mask comprises a first set of two arrays of beamlets oriented substantially parallel to each other, and a second set two arrays
20 of beamlets oriented at an angle, for example 90 degrees, relative the first set of two arrays.

The first set of two arrays is arranged so that a second array of beamlets is offset relative to a first array of beamlets, such that when the mask is transitioned the second array of beamlets will fill the gap
25 between the first array of beamlets and slightly overlap the first array of beamlets.

A method of using the mask to accomplish a 2N processing is also provided.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a view of a 2 + 2 mask design.

5 Fig. 2 shows a region of material prior to SLS processing.

Fig. 3 shows the region of material during a first irradiation exposure.

Fig. 4 shows the region of material following the first irradiation exposure and crystallization.

10 Fig. 5 shows the region of material during a second irradiation exposure.

Fig. 6 shows the region of material following the second irradiation exposure and crystallization.

15 Fig. 7 shows the region of material during a third irradiation exposure.

Fig. 8 shows the region of material following the third irradiation exposure and crystallization.

Fig. 9 shows the region of material during a forth irradiation exposure.

20 Fig. 10 shows the region of material following the forth irradiation exposure and crystallization.

Fig. 11 is a view of a 2 + 2 + 2 + 2 mask design.

Fig. 12 is a view of a portion of a mask design.

Fig. 13 is a view of one alternative 2 + 2 mask design.

DETAILED DESCRIPTION OF THE INVENTION

Fig. 1 is one embodiment of a mask 10 for a 2 + 2 shot process, which eliminates the need to rotate the substrate ninety degrees relative to the mask. Systems that rotate the substrate ninety degrees relative to the mask require complicated stage or mask retaining systems. Also it is difficult to achieve a precise ninety degree rotation, to the tolerance desired to produce optimal crystal structures. The precision of modern mask design allows the mask 10 to produce sets of beamlets which are much more precisely ninety degrees relative to another set of beamlets. This allows the mask design 10 to produce crystals that have more precisely orthogonal structures.

The mask 10 comprises a first set of slits 12 and a second set of slits 14, which are at a desired angle relative to the first set of slits. In one embodiment, the desired angle may be ninety degrees. The first set of slits consist of two arrays of beamlets, a first array of beamlets 16 and a second array of beamlets 18. The first array of beamlets 16 and the second array of beamlets 18 are preferably arranged adjacent to each other, substantially parallel to each other, and offset relative to each other with a slight overlap. The two arrays of beamlets that comprise the first set of slits 12 may be used in a first 2-shot process. For illustration, a laser source (not shown) is projected through the first array of beamlets 16 to crystallize a layer of material (not shown). The mask 10 is then stepped in the direction indicated by the arrow in Fig. 1. The second array of beamlets 18 is then used to crystallize the layer of material. The crystallized region formed by the first array of beamlets 16, and the crystallized region formed by the second array of beamlets 18 may intersect to form a continuous crystallized region. The intersection of the

crystallized regions may be accomplished by having a slight overlap of the crystallized regions for the first array of beamlets and the second array of beamlets.

As the mask 10 is moved again in the direction indicated by the arrow, the second set of slits will be projected, at least partially, over regions of material which have previously been crystallized by the first set of slits. The second set of slits comprises a third array of beamlets 22 and a fourth array of beamlets 24. The third array of beamlets 22 and the fourth array of beamlets 24 are preferably parallel to each other. After the third array of beamlets 22 has been used to crystallize portions of a region of material, the mask 10 is moved again. The forth array of beamlets 24 then slightly overlaps the regions crystallized by the third array of beamlets and crystallizes this region. The second set of slits effectively produces a second 2-shot process. Accordingly, the mask 10 shown in Fig. 1 accomplishes a 2 + 2 process without rotating the stage relative to the mask. As shown, the first set of slits is oriented horizontally and the second set of slits is oriented vertically. It is also entirely possible, to have the first set of slits oriented vertically and the second set of slits oriented horizontally.

Fig. 2 shows a region of material 30 that has been deposited over a substrate. The material is preferably amorphous material although it may contain microcrystals or be polycrystalline. The material is preferably silicon, germanium, copper, silicon germanium, or aluminum.

Fig. 3 illustrates irradiation of regions exposed by the first array of beamlets 16. The irradiation is provided by a suitable irradiation source, including an electron beam, ion beam or laser irradiation. If laser irradiation is used the source may be a uv laser, such as an excimer laser.

An excimer laser may be used at 308 nm for example. The region of material under the beamlets crystallizes by melting and solidifying. The region preferably crystallizes from the edges of the beamlets inward toward the center of the beamlets.

5 Fig. 4 shows regions 40 crystallized by the first shot. The adjacent regions 42 remain in essentially their as deposited condition, which may be amorphous. After the regions 40 have been crystallized the mask 10 is advanced.

10 Fig 5 illustrates irradiation of regions exposed by the second array of beamlets 18. The second array of beamlets 18 preferably irradiate the adjacent regions 42 with a slight overlap into the previously crystallized regions 40. The adjacent regions 42 are then crystallized. This corresponds to the second shot in a two shot process. Although a 2-shot process is shown, it is also possible to use additional shots to
15 crystallize the material in smaller segments. For example, a three shot process could be used.

 Fig. 6 shows regions 42 crystallized by the second shot, along with regions 40 which were crystallized by the first shot. The resulting crystallized material is characterized by directional effects of
20 crystallization illustrated by the grain boundaries 46, along with high angle crystal boundaries 48 at the centerline of each beamlet, as denoted by the dotted line.

 To reduce the directional effects in the crystallized material. The material may be recrystallized at a different angle. This is
25 accomplished by advancing the mask 10, and irradiating the crystallized material with the third array of beamlets 22. The third array of beamlets is oriented at an angle relative to the first array of beamlets and the

second array of beamlets 18. The angle is preferably 90 degrees, as shown in Fig. 7.

Fig. 8 shows regions 50 following crystallization. It should be noted that the directional effects in regions 50 have been reduced. Those in the adjacent regions 52 still show the directional effects of the previous crystallization process, also referred to as the first 2-shot process. The mask 10 is then advanced again.

Fig. 9 illustrates the forth array of beamlets 24 irradiating the adjacent regions 52 with a slight overlap into the regions 50 which were crystallized using the third array of beamlets 22.

Fig. 10 shows the material following irradiation using the forth array of beamlets 24. Irradiation with the third array of beamlets 22 and the forth array of beamlets 24 corresponds to a second two shot process. The mask 10 has enabled the completion of a 2+2 process without the need to rotate the mask and stage relative to each other. Although, some directional effects remain, the directional effects have been significantly reduced.

The use of the mask 10 has allowed a 2+2 process to be completed without the need to rotate the mask relative to the material. This improves throughput, reduces the complexity of the stage or mask system; and provides greater precision in the angular alignment of the masks with respect to each other.

The mask 10 can be expanded to allow for further processing such as a 2+2+2 process, or 2+2+2+2 process, etc. Fig. 11 shows the mask 10 for use in a 2+2+2+2 process. Additional 2-shot processes, may further reduce directional effects and improve the overall crystal characteristics of the crystallized material. Multiple 2-shot processes can be referred to as a

2N process, where N is the number of 2-shot processes. For the mask shown in Fig. 11, N equals 4. There may eventually be a point of diminishing returns at which point no measurable improvement in material is reached for additional crystallization shots. Provided that the irradiation source has the ability to provide sufficient power to fully utilize the entire mask, throughput may not be adversely affected by adding additional 2-shot processes.

Referring now to Fig. 12, which shows a view of adjacent beamlets taken from the first and second array of beamlets. Each beamlet has a width (W), a gap (g) and an overlap (S). The gap (g) is between adjacent elements is preferably designed to be the width (W) minus two times the overlap (S). The breadth (d) of the beamlets in the first and second arrays of beamlets should be greater than the step size between irradiation pulses. Although, there is no required upper limit on the breadth, the breadth is preferably only slightly greater than the step sizes between irradiation pulses to minimize the amount of overlap from one irradiation pulse to the next.

Referring again to Fig. 1, in this illustrated embodiment, the size of the steps between irradiation pulses is constrained by the distance across of the third array of beamlets 22 and the distance across the fourth array of beamlets 24, which preferably have the same number of elements. In a preferred example, the step size would correspond to the number of elements in the array times the combination of the width of each element (W) and the gap (g) between adjacent beamlets. There is a gap 60 between the third array of beamlets 22 and the fourth array of beamlets 24. The distance across this gap is preferably the sum of the width (W), plus the gap (g), minus the overlap (S), which reduces to

2W - 3S, since the gap (g) is related to W and S as described above. The space between the first array of beamlets 16 and the second array of beamlets 18 is not critical. The space between the third array of beamlets 22 and the second array of beamlets 18 is also not critical.

5 For purposes of illustration, the width (W) may be on the order of between approximately 3 and 5 micrometers. The overlap (S) may be on the order of between approximately 0.25 and 1 micrometer.

Referring again to Fig. 11, the mask design can be extended for use in connection with any arbitrary number of 2-shot scans, such as
10 2+2+2, 2+2+2+2, etc. Fig. 11 shows one possible embodiment of a 2+2+2+2 mask design. Based upon the relationships described above one of ordinary skill in the art will be able to determine the necessary spacing of elements.

Referring now to Fig. 13, in alternative embodiment the first
15 array of beamlets 116 and the third array of beamlets 118 are designed to overlap slightly to crystallize crystallize material in one direction. While, the second array of beamlets 122 and the forth array of beamlets 124 irradiate at a second angle, preferably 90 degrees, relative to the first and third array of beamlets. Preferably the spacing will be optimized so that
20 with the proper stepping distance the second array of beamlets 122 and the forth array of beamlets 124 will slightly overlap. This is just one exemplary embodiment to illustrate that the present invention is not limited to a single disclosed embodiment.

Rather, the scope of the invention will be determined by the
25 broadest allowable interpretation of the following claims.